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Advanced Mobile Phone Service:

Control Architecture

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The cellular concept used in the Advanced Mobile Phone Service (AMPS) system to achieve spectrum efficiency requires a complex and flexible distributed system control architecture. Three major subsystems serve as the control elements: the mobile unit, the cell site, and the switching office. System control functions are partitioned among these subsystems to handle the following AMPS control challenges: interfacing with the nationwide switched telephone network, dialing from mobile units, supervising calls from mobile subscribers in the presence of noise and co-channel interference, performing call setup functions including paging and access, and locating and handing off mobiles between cell sites. This paper explains the techniques used to achieve the control functions of the three major subsystems and the ways they in turn participate in control of the total AMPS system.

I. INTRODUCTION

The cellular concept, which achieves radio spectrum efficiency through the technique of frequency reuse, requires a grid of control elements (cell sites) distributed throughout a mobile coverage area to serve as the interface between the large numbers of moving customers and the nationwide switched telephone network. Meeting these requirements in a cost-effective manner and providing a framework for offering a variety of services to AMPS customers requires a complex yet flexible control architecture.

Before proceeding with our description of the system control architecture, which draws heavily on earlier investigations,[1-3] it will be helpful to look at some of the important system interfaces with the nationwide switched (wire-line) telephone *network* and with mobile *users.*

II. SYSTEM INTERFACES

2.1 Network interface

A single AMPS system is designed to serve customers within a given geographical area, known as a Mobile Service Area (MSA). This usually corresponds to a metropolitan area including a central city, its suburbs, and some portion of its rural fringe (see Fig. 1). However, it could encompass a portion of an extremely large metropolitan area or perhaps two or more cities located relatively close together.

Mobile customers are expected to subscribe to service in a specific MSA. While operating within its boundaries, a customer is termed a "home mobile." Outside this area, the customer is termed a "roamer." An objective of AMPS is to provide dial access between home mobiles and any other telephone (mobile or land-line) reached through the wire-line telephone network. Another objective is to provide access, as automatically as possible, to and from roamers. These goals are achieved by assigning each mobile customer a standard ten-digit telephone number composed of a three-digit area code plus a seven-digit directory number. This enables an AMPS system to interface with tbe wire-line telephone network using standard trunking methods (Fig. 2) and permits calls to be handled with standard telephone routing and signaling techniques.

2.2 User interface

AMPS radio links carry call control information in addition to voice communication. The customer's identification and the dialed digits (network address) are two call control items that must be supplied in a digital mode to the local system on every call from a mobile. Known as "preorigination dialing," the dialing sequence takes place before the mobile unit's first communication with the local system. A mobile customer dials the telephone number of the party being contacted into a register in the mobile unit, thus recording it in the unit's memory.

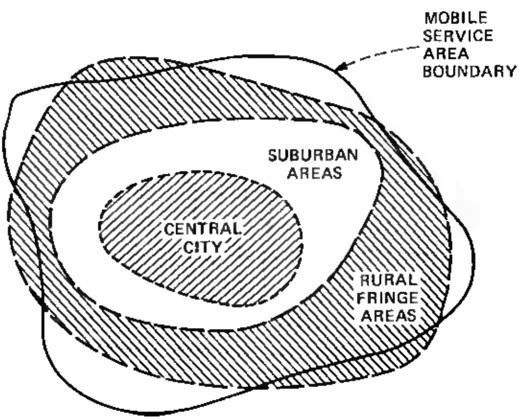


Fig. 1—Typical mobile service area.

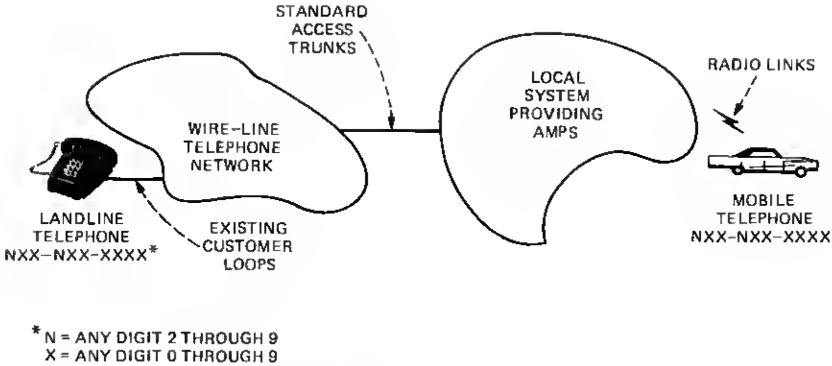


Fig. 2—AMPS system interfaces.

The customer then initiates the communication with the land portion of the system according to procedures outlined in Ref. 4.

One major advantage of preorigination dialing is that a customer can dial at a slow rate without tying up a valuable radio channel. If a mistake is made, the customer can "erase" the dialed digits and redial the correct number. Only when the number is completely assembled and stored is the radio channel used, and then the number is sent as rapidly as possible in coded form along with other call-processing information.

The mobile telephone and the land portion of the system also exchange other information, such as the unit's supervisory state, the cell site being used, and the designated voice channel. These items are discussed in later sections.

III. SYSTEM CONTROL ELEMENTS

The three major system control elements are the mobile unit, the cell site, and the switching office.

3.1 The mobile unit

In addition to transmitting network address information, the mobile unit performs other control and signaling functions, which are discussed in Section IV. As noted in Ref. 5, the mobile unit is tunable on system command to any channel in the RF spectrum allocated to AMPS at any one of four power levels as pre-programmed. To perform these control and signaling functions, its design will most likely include a microprocessor.

3.2 The cell site

To achieve the grid of small coverage areas from which the cellular concept takes its name, land-based radios are located at cell sites throughout the mobile coverage area, as described in Ref. 5. Each cell site processes the signals to make them suitable for transmission

between the wire-line network and the radio network for all mobile telephones interfacing with it. This requires real-time control, which is accomplished with stored-program techniques. In addition, each cell site performs other control and signaling functions discussed below.

3.3 *The Mobile Telecommunications Switching Office*

The Mobile Telecommunications Switching Office (MTSO) serves as the central coordinator and controller for AMPS and as the interface between the mobile and the wire-line network. As described previously, all information exchanged over this interface employs standard telephone signaling. Hence, standard switching techniques are required within the MTSO. In addition, the MTSO must (*i*) administer radio channels allocated to AMPS, (*ii*) coordinate the grid of cell sites and moving subscribers, and (*iii*) maintain the integrity of the local AMPS system as a whole. These new switching functions require extensive use of stored-program technology within the MTSO.

3.4 *Interconnection of subsystems*

Interconnection of the three major control elements is shown in Fig. 3. The mobile telephone communicates with a nearby cell site over a radio channel assigned to that cell. The cell site, in turn, is connected by land-line facilities to the MTSO, which interfaces with the wire-line network. As Fig. 3 also indicates, a considerable amount of data is exchanged between pairs of AMPS control elements. For instance, call setup data are exchanged between the mobile telephone and the cell site over radio channels reserved for this purpose. The voice channels also carry data to control and to confirm various mobile telephone

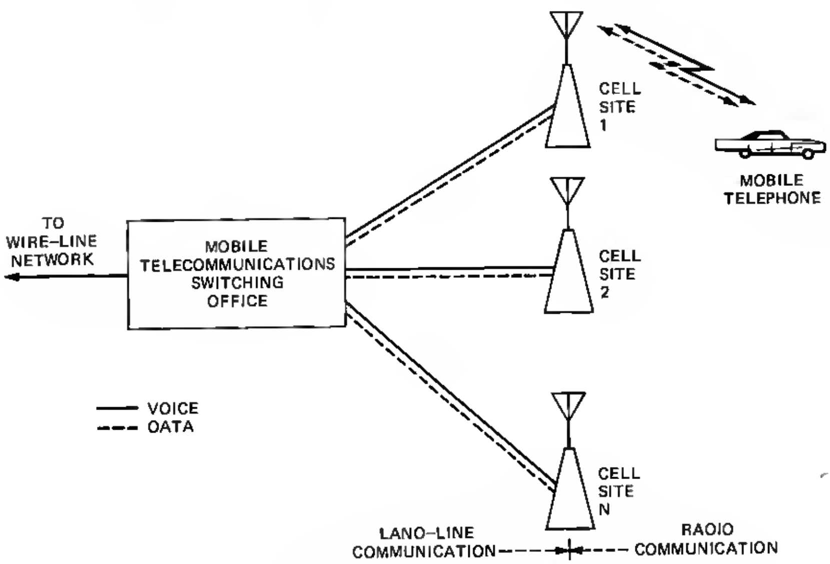


Fig. 3—AMPS system control elements.

actions. Between the cell site and the MTSO, separate facilities carry data to handle numerous call-processing and system integrity functions. All these functions are discussed below and in subsequent articles. In particular, Section VI of this paper presents scenarios of call setup sequences; we choose first to describe some of the general techniques and requirements of AMPS control.

IV. CONTROL TECHNIQUES

This section describes several important control techniques required by the cellular concept. These techniques relate to the functions of supervision, paging and access, and seizure collision* avoidance. Because of the distributed nature of the cellular plan, the important control function of ensuring system integrity (i.e., reliability and availability) is sufficiently broad in scope to require separate treatment (see Ref. 6).

4.1 Supervision

Classical land-line telephony defines supervision as the process of detecting changes in the switch-hook state caused by the customer. Mobile telephone supervision includes this process but has the additional task of ensuring that adequate RF signal strength is maintained during a call.

In a cellular system where intra-system interference is anticipated, the older mobile telephone technique of using a combination of RF carrier and a burst of tone cannot be used for supervision. As sketched in Fig. 4, some interfering signal will exceed typical values of the desired signal a significant fraction of the time. This is particularly bothersome at the end of a call when the desired mobile unit's transmitter must be turned off, and a burst of tone sent just prior to that time could be missed. Under these conditions, a false supervisory indication (caused by a co-channel interferer) would be created. The AMPS system uses a combination of a tone burst and a continuous out-of-band modulation for supervisory purposes. These are known respectively as signaling tone (ST) and supervisory audio tone (SAT).

4.1.1 Supervisory audio tone

Three SATs are set aside at 5970, 6000, and 6030 Hz. Only one of these is employed at a given cell site. The concept calls for using a SAT much as a land telephone uses dc current/voltage: A mobile unit receives a SAT from a cell site and transponds it back (i.e., closes the loop). The cell site looks for the specific SAT it sent to be returned; if some other SAT is returned, the cell site interprets the incoming RF

* Collision, as used here, means the loss of calls because of simultaneous arrival of two or more control messages.

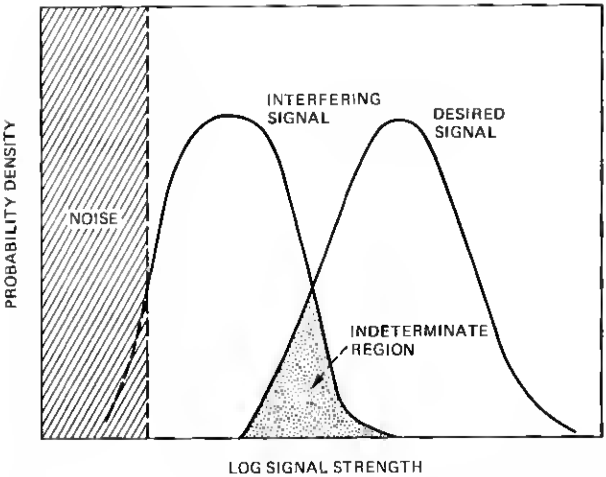


Fig. 4—Relative signal-strength distribution of desired and interfering signals.

power as being corrupted by interference, either in the land-to-mobile or in the mobile-to-land path (see Ref. 5).

In Fig. 5, we can see how the use of three SATs effectively multiplies the D/R (co-channel reuse) ratio for supervision by $\sqrt{3}$.* For example, given a voice channel reuse factor of $N = 7$, a cell site with both the same RF channel set and the same SAT is as far away as if N were 21. This three-SAT scheme provides supervision reliability by reducing the probability of misinterpreted interference (same SAT and same RF channel).

The selected SAT frequencies are close together so that one phase-locked tracking filter can lock onto any of them. They are distant from the voice band by a factor of 2, so that filtering SAT from voice is relatively easy and so that intermodulation products are controllable. The FM deviation of the SAT is ±2 kHz.

4.1.2 Signaling tone

Signaling tone (chosen to be 10 kHz) is present when the user is (*i*) being alerted, (*ii*) being handed off, (*iii*) disconnecting, or (*iv*) flashing for mid-call custom services (e.g., hold). Signaling tone is used only in the mobile-to-land direction. Figure 6 tabulates the various supervision states of the mobile when on the voice channel, as detected by the land portion of the system.

4.1.3 Locating

Another aspect of supervision with no counterpart in land line telephony is the function of locating. As discussed in Ref. 5, locating

* It is shown in Ref. 5 that D/R is proportional to $N^{1/2}$; thus, if $N_2/N_1 = 21/7$, then $D_2/D_1 = \sqrt{3}$.

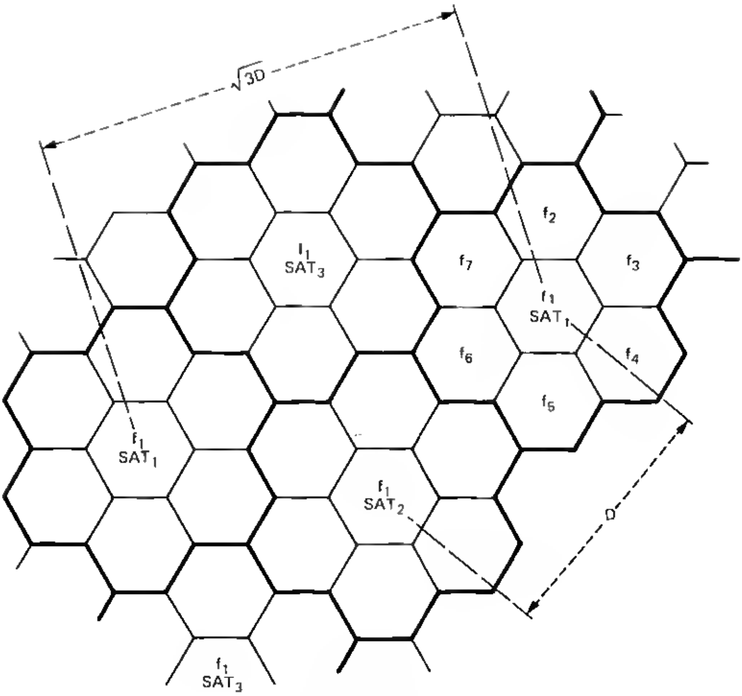


Fig. 5—SAT spatial allocation.

	SAT RECEIVED	SAT NOT RECEIVED
ST ON	MOBILE ON-HOOK*	MOBILE IN FADE OR MOBILE TRANSMITTER OFF
ST OFF	MOBILE OFF-HOOK	

SAT = SUPERVISORY AUDIO TONE
ST = SIGNALING TONE

*NOTE: RING CONFIRMATION REQUIRES THE MOBILE TO DELAY ST UNTIL THE RING ORDER IS RECEIVED.

Fig. 6—Supervision decisions made at cell site.

and handoff serve to keep the signal strength from a mobile unit at a high level during a call so that (*i*) the mobile's average S/I (signal-to-interference) ratio is adequate for its own good communication, and

(*ii*) other active mobiles do not experience high co-channel or adjacent-channel interference.

The methodology for locating requires two measurements. One is a measurement of the RF signal strength on appropriate channels, made using a tunable logarithmic receiver located at each cell site. The other is a measurement of gross range (based on round-trip delay of SAT), made on each active channel using the voice channel radios at the cell sites. Analysis of this information at the MTSO determines whether a change of channels and/or cell sites (handoff) is required. Additional details concerning locating are found in Ref. 7.

4.2 Paging and access (setup channel plan)

Seeking a called mobile unit that is at some unknown position in a service area is similar to the function performed vocally by persons called pages. Thus, the term "paging" is used in AMPS to describe the process of determining a mobile's availability to receive a given incoming call. The complementary function of beginning a call, performed by a mobile unit, is termed access. This involves (*i*) informing the system of the mobile's presence, (*ii*) supplying the system with the mobile's identification and the dialed digits, and (*iii*) waiting for a proper channel designation.

Two techniques are available to perform these paging and access tasks: (*i*) the special calling-channel method and (*ii*) the voice-channel method. The latter method, employed by older land mobile systems presently in service,[8] uses an "idle tone" to indicate which of several functionally identical channels is available to serve a new call, first for signaling, then for voice; the special-channel method, which dedicates channels either to the paging and access function or to the voice function, is used in the maritime and the air-ground services.[9] In a cellular system with many thousands of users and hundreds of channels and where the mobile unit can be made to scan the dedicated channels rapidly, the special calling-channel method is necessary because the information needed for the home/roam decision by the mobile cannot be handled by the single tone of the voice-channel method. Therefore, the AMPS control plan uses a set of special channels called setup channels for paging and access functions. These channels are distributed among the cell sites in an orderly way based on S/I considerations similar to those described in Ref. 5.

Plans for organizing use of the setup channel, based on the traffic assumptions reflected in Table I, take into account the differing demands placed on the system by paging and access. Paging information must be spread equally over the entire MSA. The information capacity requirements for paging will grow in proportion to the number of customers; however, splitting cells as described in Ref. 5 will not help to increase the capacity, since each point in the MSA needs all tbe paging information. The access requirements also increase with tbe

Table I—Traffic assumptions (based on a limited amount of early data from present-day service)

Calling rate	1 call/subscriber/busy-hour
Answer rate	Half of all attempts toward a mobile elicit a response
Traffic direction	60 percent mobile-originated 40 percent mobile-completed
Home/roam ratio	4:1
Mean rate of call arrival	1/second in densest cells

traffic, but access capacity increases with cell-splitting since each cell in the MSA needs the access information only for mobiles in that cell.

4.2.1 Access requirements

The following are the requirements on the access process:

(*i*) The capacity to handle access attempts must relate to the number of users. In areas saturated with access traffic, we expect this traffic to arrive randomly at about one arrival per second. This assumption should hold for cells of both the largest and the smallest radii. Furthermore, we expect each user to average 0.6 origination per hour, based on present-day usage statistics.

(*ii*) It must not place undue demands on the real-time processing capabilities of either the MTSO or the cell sites.

(*iii*) It must be accurate in the face of (*a*) co-channel interference from other cells and (*b*) collisions, already defined as the occasional arrival of two or more requests for service at the same time.

(*iv*) It must be stable (i.e., some rare overload situation must not cause the system to enter a state from which it cannot recover quickly).

Since the setup channels represent an expense both in capital and in channel resource (i.e., they subtract from the total reserve of channels), it is important to use these carefully and flexibly even though future traffic loads for paging and for access are not accurately known.*

4.2.2 Paging requirements

Current assumptions concerning future paging requirements are that the process must:

(*i*) Be able to handle 0.8 page per user per busy hour, of which half go unanswered. (This estimate is based on a sample of present-day users.)

(*ii*) Provide complete number flexibility to permit nationwide roaming and to accommodate any of the ten-digit telephone numbers possible today. (This assumption requires a 34-bit binary number for mobile identification.)

* Note, however, that signaling via "idle tone" would also represent an expense in that it adds channel holding time to calls in both directions.

(*iii*) Be capable of serving some unknown future demand (several hundred thousand users) while remaining economical in small cities with a user population of one thousand or less.

4.2.3 Setup channel plan

The plan that has evolved from these requirements allows paging and access functions, for the sake of economy, to be combined on the setup channels for the early years of growth when large cells with omnidirectional antennas are used. As the system grows, however, with cell splitting and the change to cell sites using directional antennas, more setup channels will be needed to handle the access function. The omnidirectional antennas would continue to handle the paging functions. Therefore, paging and access become separated when the first cell split occurs.

The paging messages themselves contain the binary equivalent of the mobile unit's directory number. Since a large amount of paging information has to be sent, efficient design suggests that the data be organized into a synchronous format (described later) of fixed-length words and synchronizing pulses. When paging is not needed, the cell site adds "filler text" in its place, merely to preserve the synchronous format.

Another type of message, called the "overhead word," is also sent periodically as part of the paging data stream to give the mobile certain descriptive information about the local system. The use of the overhead word permits flexibility in local system parameters (which are a function of local subscriber growth rates and traffic characteristics). These parameters can then be varied as actual field experience dictates. The overhead word includes:

(*i*) The MSA identification (called the Area Call Sign) to permit the automatic roaming feature.

(*ii*) The cell site's SAT identification.

(*iii*) A parameter (called N) which specifies the number of setup channels in the repeating set (the frequency reuse factor*). See item (*ii*) in Section 6.2.

(*iv*) A parameter (called CMAX) which specifies the number of setup channels to scan when a call is to be made.

(*v*) A parameter (called CPA) which tells the mobile units whether the paging and the access functions share the same setup channels.

Figure 7 depicts how the setup channels are assigned as systems grow through various sizes. The highest 21 channels are always used for setup purposes; these are the channels all mobile units are preprogrammed to recognize as those containing the necessary system identification (overhead word) information, no matter where the unit makes a call.

* This frequency reuse factor for setup channels may be different from that for voice channels.

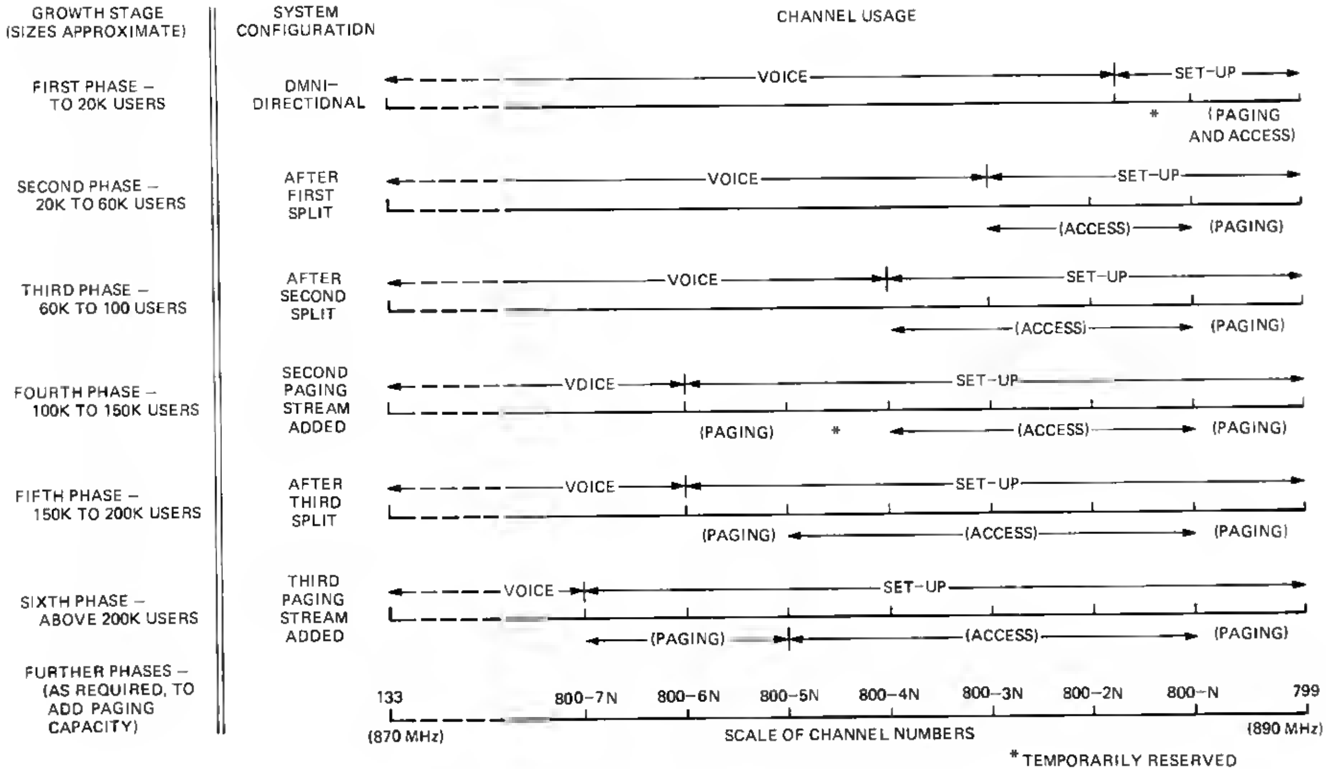


Fig. 7—Scenario for setup channel usage as users are added.

During the early period of growth (typically to about 20,000 users in a single MSA), paging and access can be combined on the setup channels. After that, cell splitting occurs and new access capability is needed. The paging capability from the original sites, with omnidirectional antennas using the original number of paging channels, remains adequate. A second cell split, at roughly 60,000 users, requires even more access capability but is expected to leave paging on the original setup channels from the original sites.

At some point, the paging capacity of the original setup channels becomes saturated. Since each channel is limited to the order of 10,000 bits/second (b/s), and since high redundancy is required to combat the fading problem in areas of low S/I, only 1200 b/s of real information can be sent. Some of this is overhead information. Thus, a practical limit is about 25 messages per second (90,000 per hour) at 100 percent loading. Actual service experience, of course, will dictate the resulting customer loading allowed (depending on how many ineffective attempts there are), but a ratio of 90,000 customers for each paging stream is probably an upper bound. Beyond that size, which should be exceeded in only a few cities by the end of the century, more setup channel sets for paging will be needed at the original omnidirectional cell sites. Logic designed into the mobile unit must anticipate the use of these additional setup channels. Mobiles will be assigned to a specific paging channel set—either the primary (highest N channels) or one of the additional sets—for use when at home, much as land telephones are assigned to central office codes within an exchange.

4.2.4 Setup channel use

Mobiles will use setup channels in the following sequence:

(*i*) When power is applied to a mobile unit, and about once a minute thereafter, it scans the top 21 channels and picks the strongest one on which to read an overhead message. This permits the mobile unit to determine if it is "home" and to retrieve the frequency reuse factor N. To receive its pages, it then rescans the appropriate* set of N channels to find the strongest channel. Since N can vary from city to city, it is read from the overhead message that is periodically being sent on all forward (cell site to mobile) setup channels.

(*ii*) When a call is to be either originated from or completed to a mobile unit, the unit must repeat the scanning process to self-locate itself to the best cell site (i.e., the strongest signal) for access. In this case, it scans CMAX channels.

(*iii*) The unit synchronizes to the word pattern on the chosen setup channel and determines if that channel is idle (discussed later). If so, it attempts an access by transmitting the necessary information to the cell site:

(*a*) If answering a page, its identification; or

* See Section 4.2.3.

(*b*) If originating a call, its identification and the dialed digits. The unit then turns its transmitter off but remains tuned and synchronized to the chosen setup channel.

(*iv*) After the land portion of the system has processed the access information, it sends a channel designation message to the mobile unit, much as a page would be sent, on the setup channel which the mobile unit had used previously. Upon receipt of this message, the mobile tunes to the designated channel, and the voice portion of the call can proceed.

4.3 Seizure collision avoidance

The initiation of a call by a mobile unit is a random event in both space and time, as the land portion of the system perceives it. Since all mobiles compete for the same setup channels, methods must be devised to minimize collisions and to prevent temporary system disruption if collisions do occur. Several techniques are used for this purpose.

First, the forward (toward the mobile) setup channels set aside every 11th bit as a "busy/idle" bit. As long as a cell site perceives legitimate seizure messages directed toward it, it sees that the "busy/idle" bit is set to "busy."

Second, the mobile sends in its seizure message a "precursor," which tells the land portion of the system with which cell site it is attempting to communicate. This is particularly necessary in systems with smaller cell sizes. For example, as explained in Ref. 5, in a system with 1-mile cells (R = 1 mile), co-channel interferers are less than five miles (D = 4.7 miles) from the serving cell site—well within the mobile's typical range of 5 to 10 miles. The information provided in the precursor is the digital-encoded equivalent of the SAT mentioned earlier; the mobile unit, having read this digital code message in the forward data stream of the setup channel being used, transmits it back to the cell site on the reverse half of the channel.

Third, before the mobile attempts to seize (access) a setup channel, it waits a random time. This cancels the periodicity introduced into the mobile seizures by the format of the setup channel messages.

Fourth, after a mobile unit sends its precursor, it opens a "window" in time in which it expects to see the channel become busy. If the idle-to-busy transition does not occur within the time window, the seizure attempt is instantly aborted.

Fifth, if the initial seizure is unsuccessful for any reason, the mobile unit will automatically try again and again at random intervals. However, to prevent continued collisions and hence system overload, a limit is placed on the number of automatic reattempts permitted.

V. DATA REQUIREMENT AND FORMATS

As a result of the control techniques described in the preceding section, considerable amounts of data are exchanged between pairs of AMPS control elements. The information requirements for the various

Table II—Requirements for information transfer

Channel	Type of Information	Number of Bits
Setup:		
Forward	Mobile page	24 or 34
	Channel designation	11
	Mobile power level	2
	Overhead (local parameters)	22 to 30
	System control	4
Reverse	Identification	56 or 66
	Dialed digits	64 (16 characters*)
	System control	4
Voice:		
Forward	Orders	5
	Channel designation	11
	Mobile power level	2
	System control	4
Reverse	Order confirmation	5
	Dialed digits (for custom-calling services)	64 (16 characters)
	System control	4

* Characters are defined as the digits 0–9, plus #, *, and other symbols reserved for future use.

channels are shown in Table II. The radio interface channels (mobile unit to cell site) differ from land channels (cell site to MTSO) not only in capacity requirements but also in the way they must be handled because of the differing nature of the noise impairments. This section describes the data requirements and formats* for the different AMPS interfaces: forward setup channel, reverse setup channel, voice channel, and land-line data link.

Before dealing with each of these interfaces in turn, we will describe common characteristics of the first three. One is the rapid fading experienced by signals as mobiles move through the complex RF interference pattern. To combat the burst errors caused by this fading, all data words are encoded and repeated several times at the source, and a bit-by-bit, 3-out-of-5 majority vote is taken at the receiver to determine the best-guess detected word to send to the decoder. The coding used on all radio channels is a shortened (63, 51) BCH† code [(40, 28) in the forward direction, and (48, 36) in the reverse direction]; this code has the capability of correcting one error while detecting at least two more, without unreasonable complexity. This type of coding scheme, along with the majority-voting technique, provides a good balance between a low miss rate (probability of not detecting a message when one is sent) and a low falsing rate (probability of detecting the wrong message).

Further description of the data channels is given in Ref. 10. In brief, however, the philosophy used is to send the data at the fastest bit rate possible over the RF channel, consistent with its bandwidth, thus filling

* For the sake of brevity, certain message details are omitted in this section.

† Bose-Chandhuri-Hocquenghem originated this linear block systematic error coding scheme; (63, 51) indicates that there are 63 bits transmitted, of which 51 are information and 12 are parity-check bits.

the channel as evenly as reasonably possible with energy. Channel capacity over and above the information needs is used up by redundancy, i.e., both by encoding and by repeating the message several times. Thus, a 10-kbs rate was chosen for the AMPS radio channels, to give a total maximum information throughput of 1200 b/s. Mobile unit cost is also an important consideration in the choice of formats.

Another characteristic which these radio channels have in common is the pair of error requirements for information transfer:

(*i*) The miss rate for messages should be in the range of 10^{-3} at S/I = 15 dB. Averaged over the entire service area, this implies a miss rate of about 10^{-4}. This miss rate is very small compared to the probability that a call will be missed because a mobile is unattended. Furthermore, it is consistent with the requirement placed on mishandled calls in the wire-line telephone network.

(*ii*) The falsing rate (incorrect data interpretation) should be less than 10^{-7} for a given message. This stringent requirement is necessary because, for example, in a system where 90,000 users are assigned to a given paging data stream, up to 45,000 mobile units might be listening to every page;* in this situation, the requirement implies that less than one transmitted page in 200 will elicit a false response (which the MTSO will be required to screen).

5.1 Forward setup channel

Data on this channel are transmitted continuously in a periodic format, so that idle mobile units can synchronize to the format to read a large volume of paging and local system information.

Details on the data format of the forward setup channel are shown in Fig. 8. The basic periodicity of the bit stream is 463 bits, summed as follows:

200 bits—Word *A* (40 bits, repeated 5 times)
200 bits—Word *B* (40 bits, repeated 5 times)
10 bits—Bit sync
11 bits—Word sync
42 bits—Busy-idle bits
463 bits

The five repeats of words *A* and *B* are interleaved to provide spacing in time, which in turn ensures partial decorrelation of bit errors between repeats of the same word. Note that a given mobile unit is not required to decode both of the two message streams; it chooses the *A* or *B* stream depending on whether its identification is even or odd.†

* This assumes that at least half the equipped mobiles are not energized at any given time.

† Determined by the last digit of its telephone number.

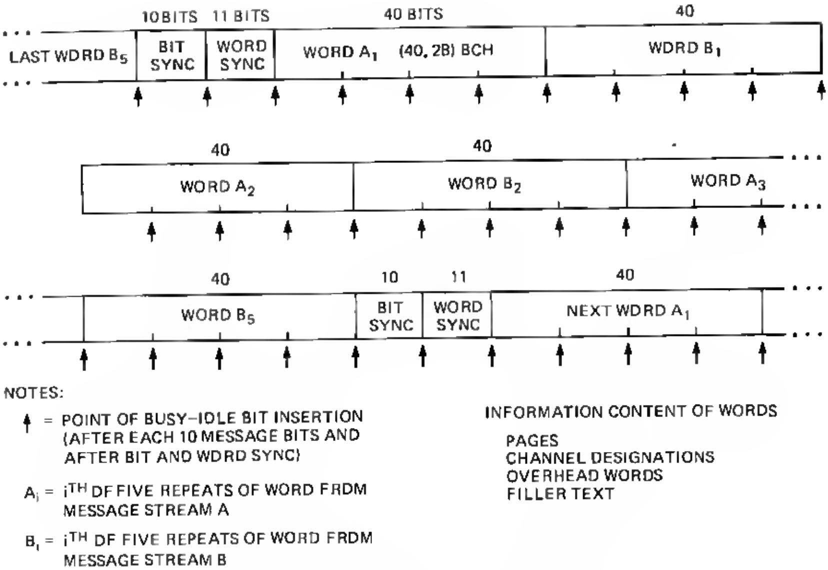


Fig. 8—Data format (forward setup channel).

5.2 Reverse setup channel

On this channel, the mobiles act in a random and competitive way to initiate calls. Both signals and interferences are turned on and off in an uncorrelated fashion.

Details on the data format of the reverse setup channel are shown in Fig. 9. A message is preceded by a 48-bit seizure precursor. Each message consists of 1 to 5 words of 48 bits each, repeated 5 times. The cell site performs a bit-by-bit, 3-out-of-5 vote to determine the 48-bit

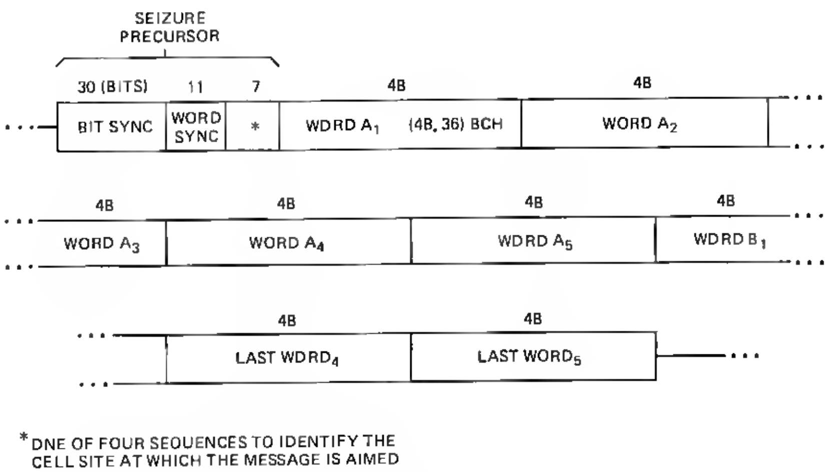


Fig. 9—Data format (reverse setup channel).

encoded word; it then evokes a decoding algorithm to correct one error if necessary (or to reject the message as uncorrectable).

5.3 Voice channel

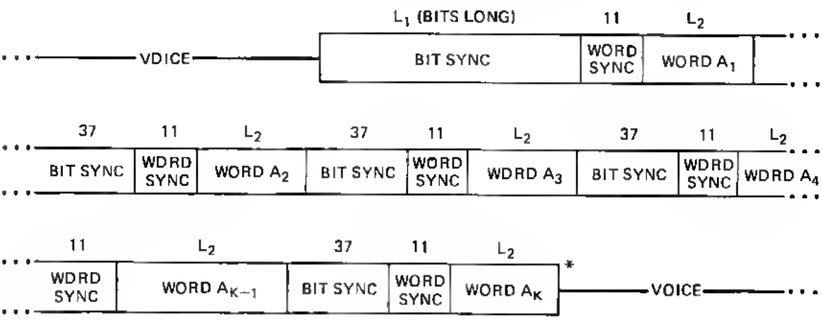
This channel is, of course, used primarily for conversation. However, data messages (primarily handoff) are also required on this channel. Unlike the reverse setup channel, a transmitted signal is always available to provide "capture" and thus suppress interfering data messages.

The technique used is "blank-and-burst": that is, the voice signal is blanked and the data are sent rapidly in a burst that uses a large part of the channel's bandwidth. The falsing rate requirement for this channel can be relaxed to 10^{-5} because the effect of falsing on this channel is similar to a mishandled call on the wire-line network (with which the 10^{-5} falsing rate is consistent).

Details on the data format of the voice channel are shown in Fig. 10. Note that messages are repeated 11 times in the forward direction but only 5 times in the reverse direction. The primary reason for this difference is that the handoff message, considered a critical function since false interpretation results in a mishandled call, is usually sent under atypically low S/I conditions.

5.4 Land-line data line

The capacity for information transfer between cell site and MTSO must be great enough to take care of a large number of functions and flexible enough to accommodate changes as the system matures. The choice of a 2400-b/s channel, with growth capability to two channels



PARAMETER VALUE

	FORWARD	REVERSE
L_1 (BITS LONG)	100±	101
L_2 (BITS LONG)	40	48
K (REPEATS)	11	5

*NOTE:
ON THE REVERSE CHANNEL, A SECOND MESSAGE (B) MAY FOLLOW WORD A_K

Fig. 10—Data format (voice channel).

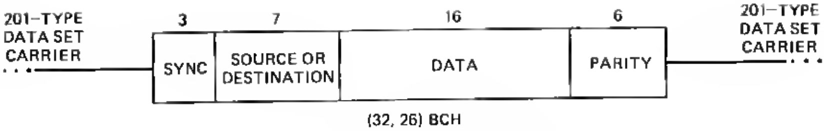


Fig. 11—Data format (land-land data channel).

in large systems and the use of the data format to be described, satisfy these qualitative requirements.

The coding scheme chosen is a (32, 26) BCH code, shortened from a basic (63, 57) BCH code. Synchronization is via a preamble embedded at the start of each message. Subtracting the 6-bit parity check and the 3-bit synchronization leaves 23 bits for information.

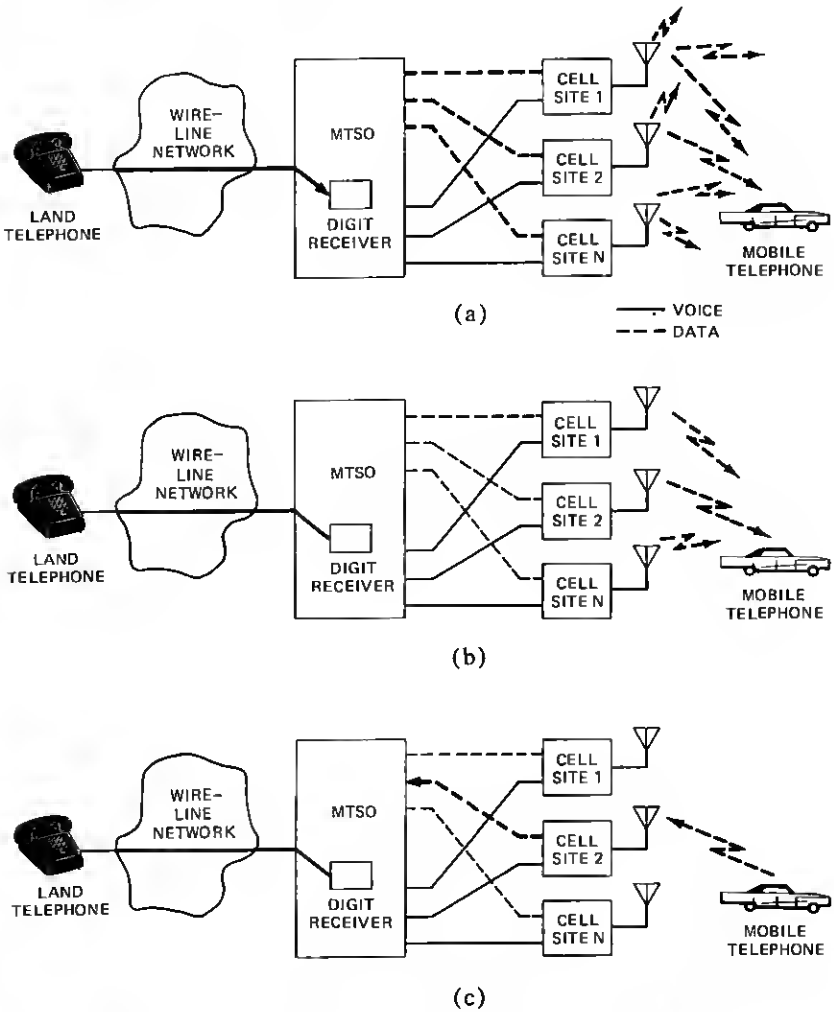


Fig. 12—Mobile-completed call sequence. (a) Paging. (b) Cell site selection. (c) Page reply. (d) Channel designation. (e) Alerting. (f) Talking.

Figure 11 is a sketch of the basic format. Each message has 16 bits for the actual data (specific commands, numbers to be transmitted, locating measurements, etc.) preceded by a 7-bit routing item, which generally takes one of three forms:

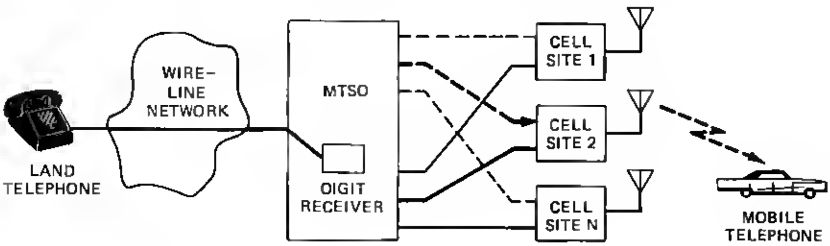
(*i*) "Source" identification for messages sent from cell site to MTSO, (e.g., setup receiver, locating receiver, voice radio).

(*ii*) "Destination" identification for messages sent from MTSO to cell site (e.g., setup transmitter, blank-and burst data unit).

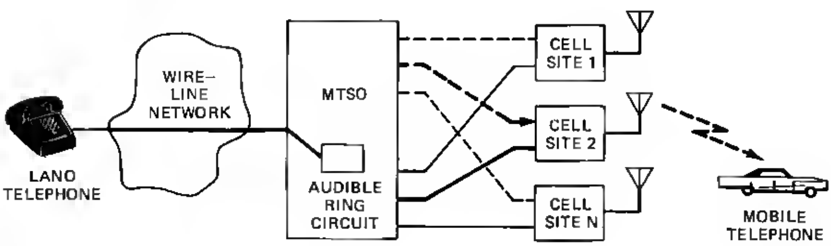
(*iii*) "AWC" (additional word coming) for multi-word messages in each direction.

VI. CONDENSED CALL SEQUENCES

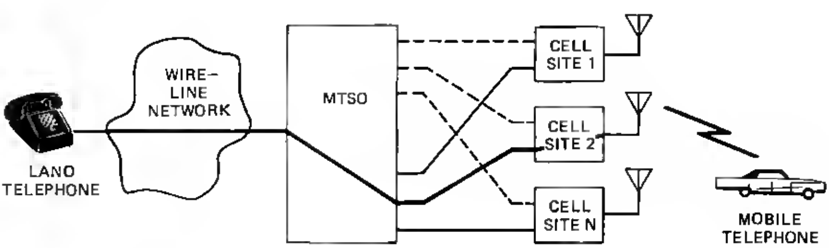
Various control functions and the major control elements of the AMPS system have been described. The ways these elements work



(d)



(e)



(f)

Fig. 12 (Cont.)

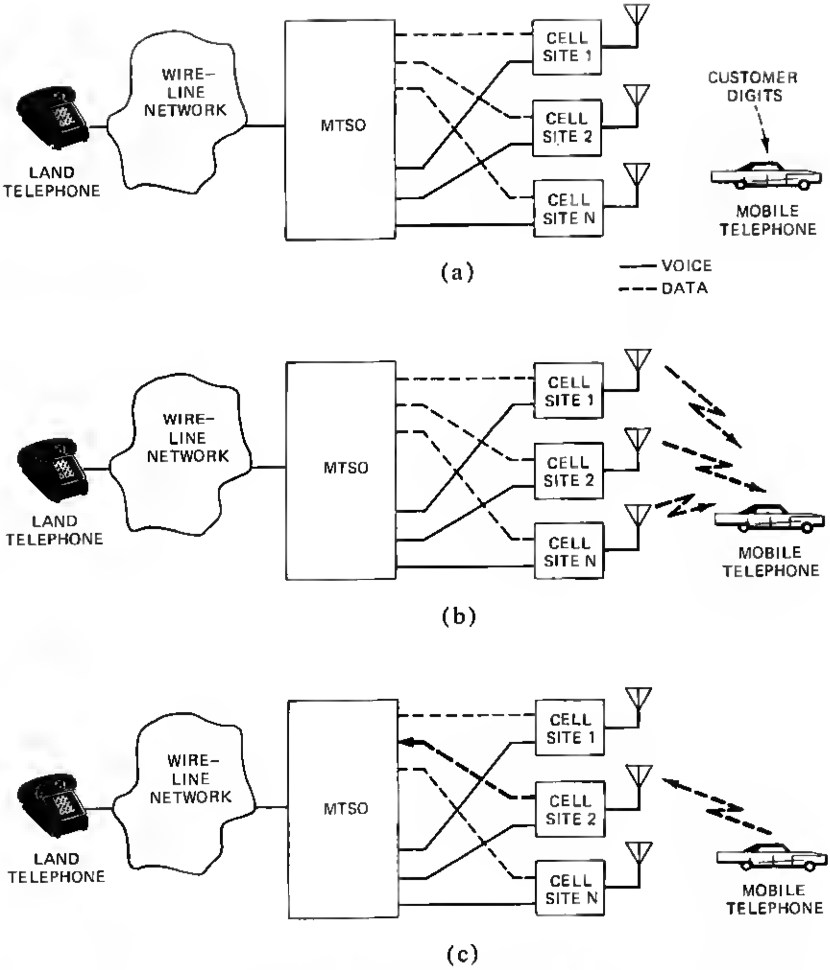
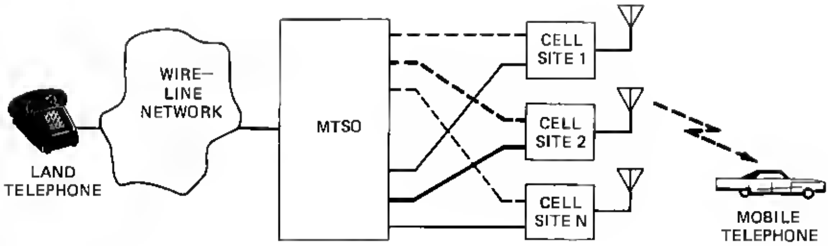


Fig. 13—Mobile-originated call sequence. (a) Preorigination. (b) Cell site selection. (c) Origination. (d) Channel designation. (e) Digit outpulsing. (f) Talking.

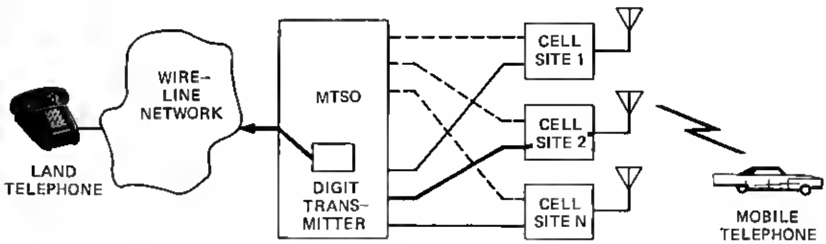
together to perform their control functions can be seen in perspective most effectively by describing rudimentary mobile call sequences. There are two basic types of mobile telephone calls—mobile-completed calls and mobile-originated calls. These are described next, in turn, to the point at which conversation occurs (talking state). Actions common to both call types are also discussed.

6.1 Initialization

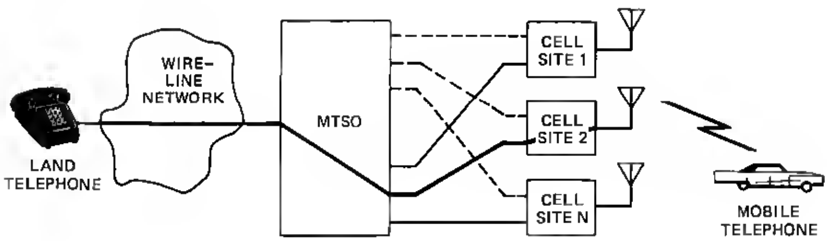
When the mobile telephone is energized, it scans the setup channels according to a program in its memory (as described in Section 4.2.4) and selects the strongest one. This channel will normally be associated with a nearby paging cell site. The mobile telephone continues to monitor the selected forward setup channel for paging messages. It



(d)



(e)



(f)

Fig. 13 (Cont.)

repeats the initialization process at regular intervals or when needed because of poor signal at the mobile, or until it is involved in a call.

6.2 Mobile-completed call

Figure 12 shows the actions required to process a mobile-completed call. There are:

(*i*) Paging: From the calling party's central office, the call is routed by standard wire-line network routing procedures to the home MTSO of the mobile. The MTSO collects the digits, converts them to the mobile's identification number, and instructs the cell sites containing paging channels to page the mobile over the forward setup channels. In this way, the paging signal is broadcast over the entire service area.

(*ii*) Cell site selection: The mobile unit, after recognizing its page, scans the setup channels used for access in the MSA, using parameters

derived from the overhead word, and selects the strongest one. The selected channel will probably be associated with a nearby cell site (usually the nearest cell site).

(*iii*) Page reply: The mobile responds to the cell site it selected over the reverse setup channel. The selected cell site then reports the page reply to the MTSO over its dedicated land-line data link.

(*iv*) Channel designation: The MTSO selects an idle voice channel (and associated land-line trunk) in the cell site that handled the page reply and informs the cell site of its choice over the appropriate data link. The serving cell site in turn informs the mobile of its channel designation over the forward setup channel. The mobile tunes to its channel designation and transponds the Supervisory Audio Tone (SAT) transmitted over the voice channel. On recognizing the transponded SAT, the cell site places the associated land-line trunk in an off-hook state, which the MTSO interprets as successful voice channel communication.

(*v*) Alerting: On command from the MTSO, the serving cell site transmits a data message over the voice channel to an alerting device in the mobile telephone which signals the customer that there is an incoming call. Signaling tone from the mobile causes the cell site to place an on-hook signal on the appropriate land-line trunk which confirms successful alerting to the MTSO. The MTSO, in turn, provides audible ringing to the calling party.

(*vi*) Talking: When the customer answers, the cell site recognizes removal of signaling tone by the mobile and restores the land-line trunk to an off-hook state. This is detected at the MTSO, which removes the audible ringing circuit and establishes the talking connection so that conversation can begin.

6.3 Mobile-originated call

Figure 13 depicts the various actions required to establish a mobile-originated call. These are:

(*i*) Preorigination: Using the preorigination dialing procedures described earlier (in Section 2.2), the customer enters the dialed digits into the mobile unit's memory.

(*ii*) Cell site selection: After the mobile unit is placed in an off-hook state, a process takes place similar to that described previously for the mobile-completed call (see item (*ii*) in Section 6.2).

(*iii*) Origination: The stored digits, along with the mobile's identification, are transmitted over the reverse setup channel selected by the mobile. The cell site associated with this setup channel receives this information and relays it to tbe MTSO over its land-line data link.

(*iv*) Channel designation: As for a mobile-completed call, the MTSO designates a voice channel and establishes voice communication with the mobile. The MTSO also determines routing and charging information at this time by analyzing the dialed digits.

(*v*) Digit outpulsing: The MTSO completes the call through the wireline network using standard digit outpulsing techniques.

(*vi*) Talking: When outpulsing is completed, the MTSO establishes a talking connection. Communication between customers takes place when the called party answers.

6.4 Other common actions

6.4.1 Handoff

Figure 14 depicts the actions common to both mobile-originated and mobile-completed calls during the important process of handoff. These are:

(*i*) New channel preparation: Location information gathered by the cell site serving the mobile, as well as by surrounding cell sites, is

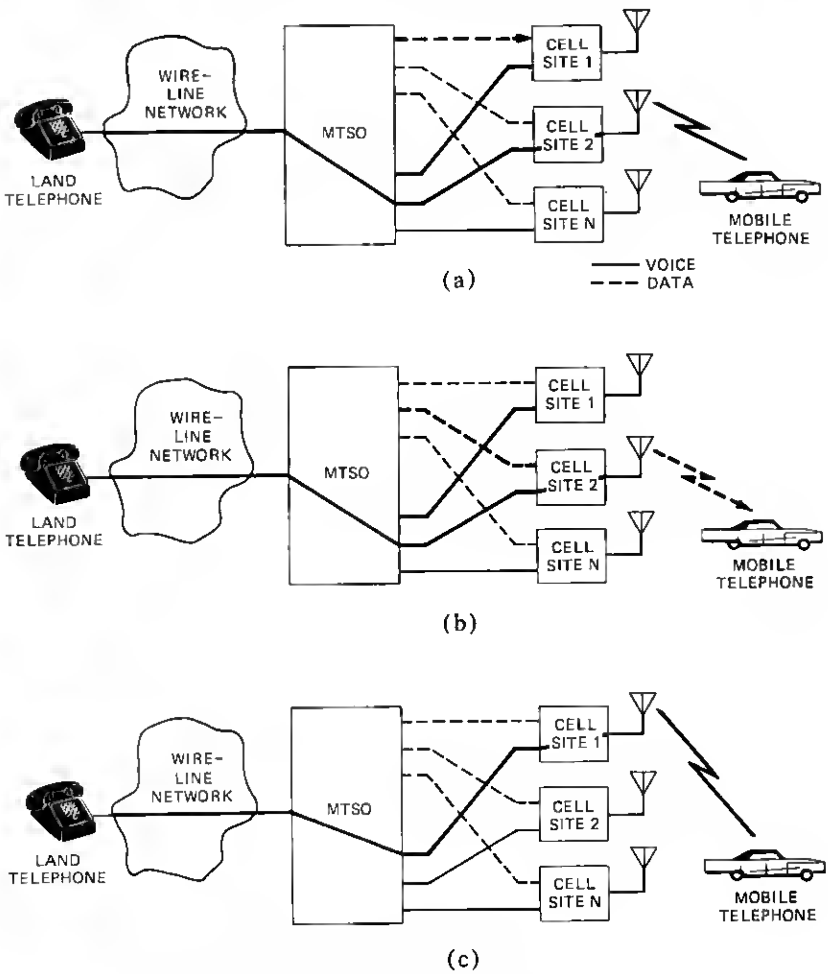


Fig. 14—Handoff sequence. (a) New channel preparation. (b) Mobile retune command. (c) Channel/path reconfiguration.

transmitted to the MTSO over the various cell site land-line data links. The data are analyzed by the MTSO, which decides that a handoff to a new cell site is to be attempted. The MTSO selects an idle voice channel (and an associated land-line trunk) at the receiving cell site and informs the new cell site to enable its radio. The receiving cell site turns on its radio and transmits SAT.

(*ii*) Mobile retune command: A message is sent to the current serving cell site informing it of the new channel and new SAT for the mobile in question. The serving cell site transmits this information to the mobile over the voice channel.

(*iii*) Channel/path reconfiguration: The mobile sends a brief burst of signaling tone and turns off its transmitter; it then retunes to its new channel and transponds the SAT found there. The old cell site,

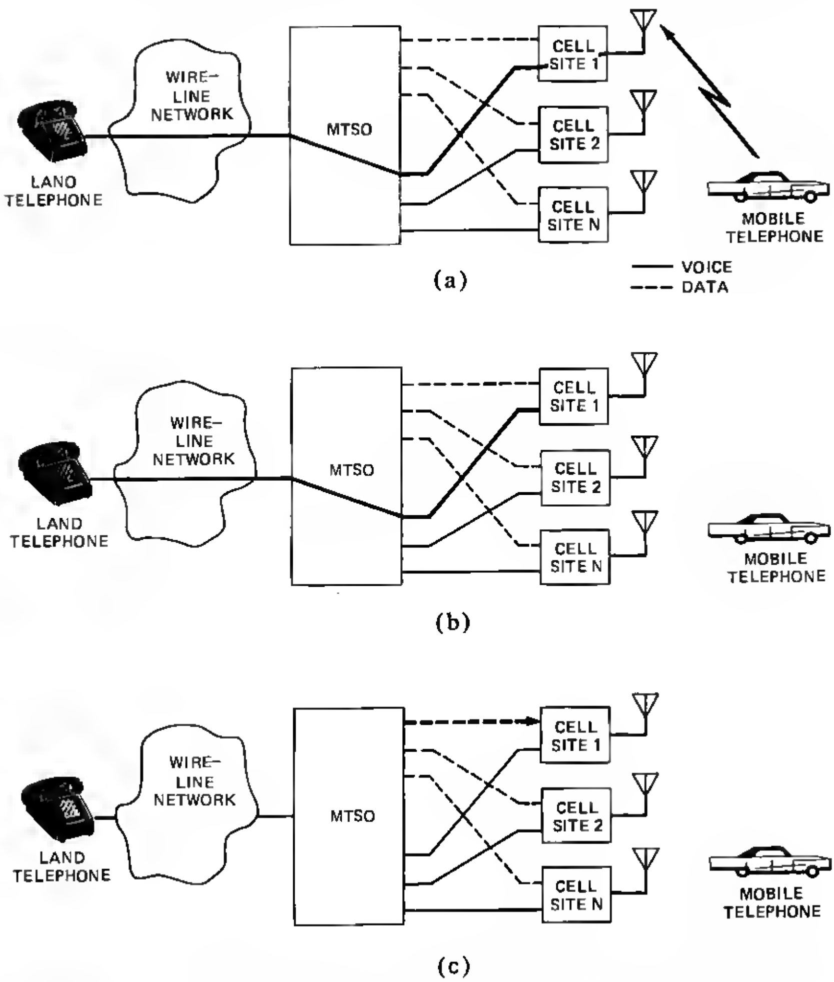


Fig. 15—Disconnect sequence (mobile-initiated). (a) Release. (b) Idle. (c) Transmitter shutdown.

having recognized the burst of signaling tone, places an on-hook signal on the trunk to the MTSO. The MTSO reconfigures its switching network, connecting the other party with the appropriate land-line trunk to the new serving cell site. The new serving cell site, on recognizing the transponded SAT on the new channel, places an off-hook signal on the associated land-line trunk. The MTSO interprets these two signals (off-hook on new trunk; on-hook on old trunk) as a successful handoff.

6.4.2 Disconnect

Figures 15 and 16 depict the actions common to both mobile-originated and mobile-completed calls during the call disconnect process. Disconnection can be initiated by either the mobile party or the land

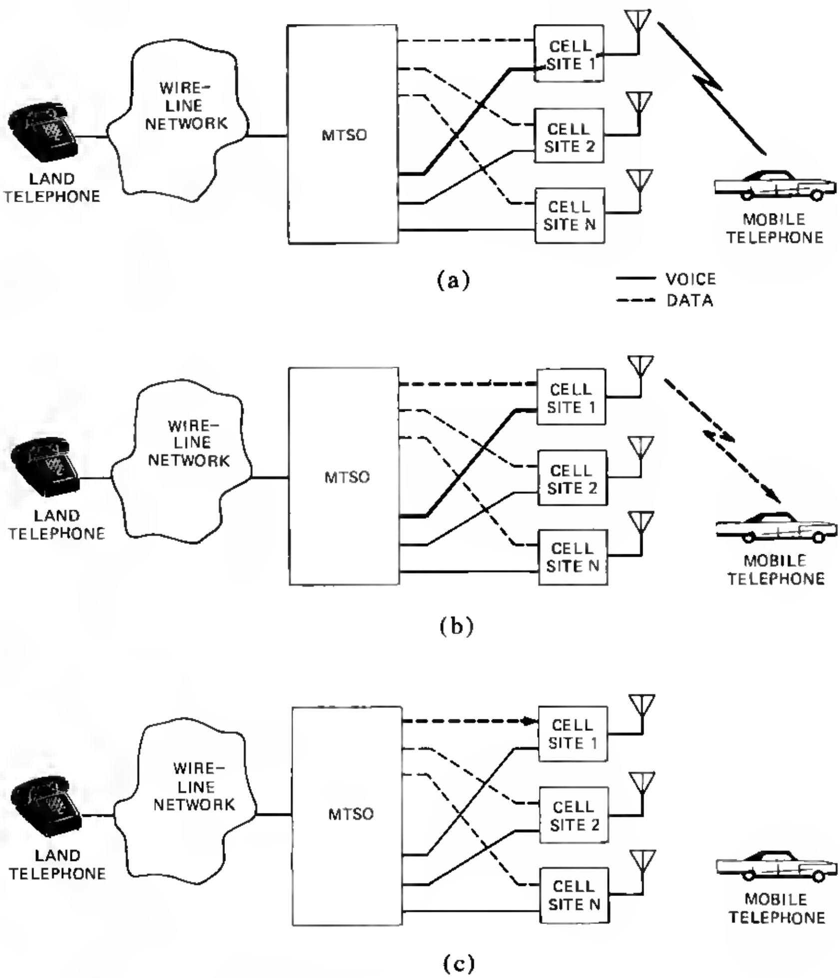


Fig. 16—Disconnect sequence (system-initiated). (a) Idle. (b) Ordered release. (c) Transmitter shutdown.

portion of the system (usually in response to an on-hook signal from a land party). The resulting actions differ somewhat.

Mobile-initiated disconnect: The actions occurring when the mobile party goes on-hook are:

(*i*) Release: The mobile unit transmits signaling tone and turns off its transmitter. The signaling tone is received by the cell site, which places an on-hook signal on the appropriate land-line trunk.

(*ii*) Idle: In response to the on-hook signal, the MTSO idles all switching office resources associated with the call and transmits any necessary disconnect signals through the wire-line network.

(*iii*) Transmitter shutdown: As the final action in the call, the MTSO commands the serving cell site over its land-line data link to shut down the cell site radio transmitter associated with the call. All equipment used on this call may now be used on subsequent calls.

System-initiated disconnect: The actions occurring when the land party goes on hook are:

(*i*) Idle: In response to the disconnect signal received from tbe wire-line network, the MTSO idles all switching office resources associated with the call.

(*ii*) Ordered release: The MTSO sends a release order data link message to the serving cell site. This cell site transmits this command to the mobile over the voice channel. The mobile confirms receipt of this message by invoking the same release sequence as with a mobile-initiated disconnect.

(*iii*) Transmitter shutdown: When the MTSO recognizes successful release by the mobile (via an on-hook signal on the appropriate land-line trunk), it commands the serving cell site to shut down the radio transmitter as described previously.

VII. SUMMARY

The Advanced Mobile Phone Service system achieves spectrum efficiency at the cost of control complexity. The control architecture resides in three widely distributed control elements: the mobile unit, the cell site, and the mobile telecommunications switching office. A typical large, mature system might have up to 100,000 mobile telephones, 50 cell sites, and a single mobile telecommunication switching office.

The three control elements work together to perform the system control functions. These include standard telephony control functions plus a set of functions resulting directly from either the cellular concept or the general radio environment. The control functions are partitioned among the control elements as shown in Fig. 17. This partitioning of functions is flexible. Because of the extensive use of stored-program technology in all the control elements, the control functions may be repartitioned to tune the system's performance as actual field service data become available in the future.

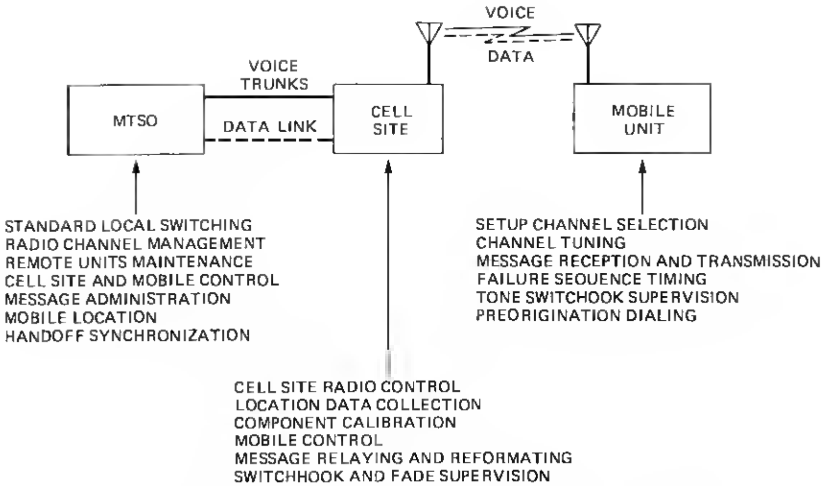


Fig. 17—Partitioning of control functions among AMPS control elements.

VIII. ACKNOWLEDGMENTS

Many people contributed to the control plan for the AMPS system. Aside from other authors in this issue, the following bear special mention: V. Hachenburg, B. D. Holm, G. D. Ott, R. J. Pennotti, S. A. Tartarone, and J. E. Wilkes.

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